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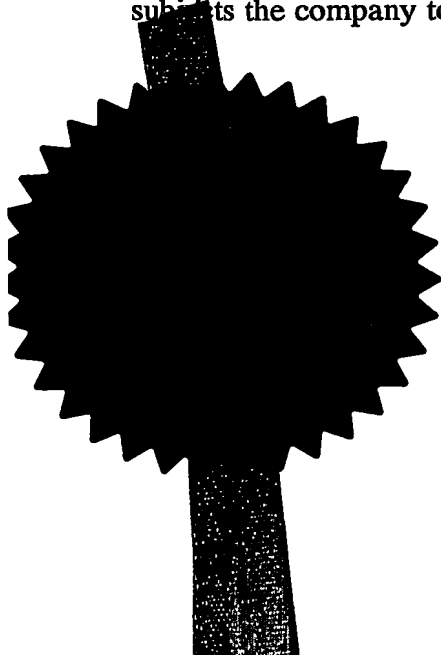
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SOLAR CELLS AND ENCAPSULATION THEREOF

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Claim(s)

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### SOLAR CELLS AND ENCAPSULATION THEREOF

[0001] This invention relates to a solar cell and a process of applying a silicone based encapsulant material onto an array of interconnected solar cells (crystalline silicon or thin film silicon) to form a solar module.

[0002] In general, solar cell modules are made by interconnecting individual solar cells and laminating the interconnected cells into an integral solar cell module. Typically, solar cells are provided with a top cover material, which may be glass, or a stiff transparent material, for example an organic fluoropolymer such as an ethylene tetrafluoroethylene (ETFE) based copolymer. External of the top cover material, i.e. remote from the cell is then provided a transparent front encapsulant. A wide variety of materials may be used as the encapsulant, a common example in the prior art being ethylene-vinylacetate copolymer (EVA). The front encapsulant is chosen to adhere to both the cover material and to a series of interconnected solar cells. A rear encapsulant is also applied to the base of each cell. The rear encapsulant may be the same material as the front encapsulant, e.g. EVA but may be transparent or any suitable colour. A rigid or, a stiff backskin is additionally provided to protect the rear surface of the module. A protective seal which covers the edges of the module, and a perimeter frame made of aluminium or a plastic material is provided to cover the seal. The frame protects the edges of the module when the front cover is made of glass.

[0003] EP 0406814 and US 6320116 both describe encapsulation systems for solar cell or photovoltaic systems. Kondo et al. (Solar Energy Materials and Solar Cells 49 (1997) pages 127 to 133) describe the use of a thermosetting organic liquid resin as a means of encapsulating amorphous silicon photovoltaic modules but does not clearly identify the resin used.

[0004] Before the frame is mounted, the module is laminated under heat and vacuum conditions which cause the layers of encapsulant material to melt, bond to adjacent surfaces, and literally "encapsulate" the solar cells.

[0005] Solar cells may be made from, for example, crystalline silicon or thin film silicon. As crystalline silicon solar cells are usually brittle, the encapsulant serves to protect the solar cells and reduce breakage when the module is subject to mechanical stress during normal usage.

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[0006] Subsequent to lamination the frame is attached to the module. Typically frames suitable for use in combination with solar cells comprise mounting holes which are provided to enable easy mounting of the resulting framed module to a suitable object in the field. Typically the mounting process will be accomplished using any appropriate mounting systems e.g. by way of screws, bolts, nuts and the like.

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[0007] Currently existing methods for solar cell module encapsulation are carried out in a batch mode. Thermoplastic sheets are melted under vacuum and subsequently laminated which makes the entire process slow and the overall cost of encapsulating the modules is high. There is therefore a long felt need to reduce the costs of this encapsulating step of the solar cells in order to reduce the overall cost of their manufacture and it will be appreciated that a continuous encapsulation process will decrease the overall cost of the module. It is also known that the cost of the encapsulant and the back skin materials represent a substantial fraction of the overall cost of each cell and/or module. The inventors have identified that the overall cost of per solar cell module may be reduced by using an alternative solution based on the use of one or more liquid encapsulants enabling a continuous encapsulation process which eliminates several stages in the current solar cell module manufacturing process.

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[0008] Currently one method used to decrease solar cell module manufacturing costs involves the replacement of the metal, typically aluminium solar cell frame with a polymeric material for both the back skin and the edging. For amorphous thin film silicon solar cell modules, polymeric frames made from moulded thermoplastic materials such as polyurethane are commonly used. These may be prepared by reaction injection moulding polyurethane to form a frame around an amorphous silicon module. Reaction injection moulding may be done in situ (i.e., on the module), this generally leads to a significant cost saving. However, this moulding process shows several disadvantages. For example, this process includes the use of a chemical precursor (e.g., isocyanate) which poses environmental hazards. This

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process also requires a mould, further adding to the overall manufacturing cost. The modules tend to be smaller because of the higher cost of the mould and the limited strength of the resulting polymeric frame. In this configuration, the encapsulant is still based on several layers of laminated thermoplastics such as EVA and a fluoropolymer such as ETFE  
5 copolymer. The only cost saving is derived from the cost reduction of the frame but potentially renders the resulting cells more brittle.

[0009] Another problem with the system currently used in the industry is the fact that thermoplastic laminates are well known to have poor adhesive properties relative to glass.  
10 This problem whilst not always initially evident often leads to gradual delamination of a thermoplastic layer from glass surfaces in a solar cell over periods of prolonged weathering. These laminates also have a low UV resistance and as such discolour, generally turning yellow or brown over the lifetime of a solar cell, leading to a non aesthetically pleasing module. Classically, a substantial amount of adhesive may often be required to reduce  
15 delamination effects and of UV screens are necessary to decrease long term discolouration.

[0010] For crystalline silicon modules, one of the main problems are the costs of the materials used, for example, the backskin material is generally expensive. There are two widely used back skin materials, both of which tend to be expensive: EVA laminate and  
20 Tedlar® a polyvinyl fluoride (PVF) and the other widely used backskin material is glass in glass/cell /glass configuration.

[0011] The inventors are seeking to overcome the above problems by providing a new solar cell module and an associated continuous process therewith which avoid the problems  
25 described above, in that the plastics laminates are replaced by a liquid encapsulant that hardens under infrared radiation or thermal cure so as to reduce or eliminate handling of laminates sheets, and eliminate the use of laminators, that increases the encapsulation batch time and cost. The present invention furthermore addresses the problem of waste generated by lamination processes, and the resulting associated materials cost.

30

[0012] In accordance with a first aspect of the present invention there is provided a solar cell module comprising a solar cell and a liquid silicone encapsulant.

[0013] The liquid silicone encapsulant in accordance with the invention preferably comprises

Component (A) 100 parts by weight of a liquid diorganopolysiloxane having at least two Si-alkenyl groups per molecule and a viscosity at 25°C of from 100 to 10,000 mPa-s;

Component (B) 20 to 40 parts by weight of a silicone resin containing at least two alkenyl groups;

Component (C) a cross-linking agent in the form of a polyorganosiloxane having at least two silicon-bonded hydrogen atoms per molecule, in an amount such that the ratio of the number of moles of silicon-bonded hydrogen to the total number of moles of silicon-bonded alkenyl groups in component is from 0.1: 1 to 1: 1;

Component (D) a platinum based catalyst wherein the amount of platinum metal in said platinum-based catalyst is from 0.01 to 500 parts by weight per 1,000,000 parts by weight of component (A).

[0014] Component (A) is preferably a liquid diorganopolysiloxane, represented by the following average unit formula:



Wherein each R is the same or different and is a monovalent hydrocarbon group, for example a linear or branched alkyl group such as methyl, ethyl, propyl, isopropyl t-butyl, and pentyl; an alkenyl group such as vinyl, allyl, or hexenyl; and an aryl group such as phenyl. "a" is a number with an average value between 1.8 and 2.3. Preferably, component (A) has a viscosity at 25°C of from 100 to 10,000 mPa-s, a molecular structure which is substantially linear although may be partially branched and a relatively low molecular weight of from 10000 to 50000, more preferably from 15000 to 30000. Preferably, component (A) comprises alkenyl terminal groups.

[0015] Examples of component (A) include

a dimethylvinylsiloxy-terminated dimethylpolysiloxane,

a dimethylvinylsiloxy-terminated copolymer of methylvinylsiloxane and dimethylsiloxane,

a dimethylvinylsiloxy-terminated copolymer of methylphenylsiloxane and dimethylsiloxane,

a dimethylvinylsiloxyl-terminated copolymer of methylphenylsiloxane, methylvinylsiloxane, and dimethylsiloxane,

a dimethylvinylsiloxyl-terminated copolymer of diphenylsiloxane and dimethylsiloxane,

a dimethylvinylsiloxyl-terminated copolymer of diphenylsiloxane, methylvinylsiloxane, and  
5 dimethylsiloxane,

[0016] Component (B) is a Silicone resin containing at least two alkenyl groups comprising  $\text{SiO}_{4/2}$  units (also known as Q units) and units selected from  $\text{R}'\text{SiO}_{3/2}$  (also known as T units),  $\text{R}'_2\text{SiO}_{2/2}$ , and  $\text{R}'_3\text{SiO}_{1/2}$  units, where each  $\text{R}'$  may be the same or different and is  
10 R or a hydrogen atom. It is preferred to disperse component (B) in a suitable solvent to ensure ease of mixing with component (A). Any suitable solvents may be used such as for example aromatic solvents such as toluene and xylene, ketones such as methyl isobutyl ketone, alcohols such as isopropanol and non-aromatic cyclic solvents such as hexane. Typically, xylene is preferred. Preferably, the silicone resin used has a viscosity of between  
15 500 to 5000 cP, more preferably between 750 and 2000cP.

[0017] Component (C) is a cross-linking agent in the form of a polyorganosiloxane having at least two silicon-bonded hydrogen atoms per molecule and has the following average unit formula:  
20  $\text{R}^i_b\text{SiO}_{(4-b)/2}$   
where each  $\text{R}^i$  may be the same or different and is hydrogen, an alkyl group such as methyl, ethyl, propyl, and isopropyl or an aryl group such as phenyl and tolyl. Component (C) may have a linear, partially branched linear, cyclic, or a net-like structure.

25 [0018] Examples of the aforementioned organopolysiloxane include one or more of the following:

a trimethylsiloxyl-terminated polymethylhydrogensiloxane,

a trimethylsiloxyl-terminated copolymer of methylhydrogensiloxane and dimethylsiloxane,

a dimethylhydrogensiloxyl-terminated copolymer of methylhydrogensiloxane and

30 dimethylsiloxane,

a cyclic copolymer of methylhydrogensiloxane and dimethylsiloxane,



an organopolysiloxane composed of siloxane units expressed by the formula  $(CH_3)_4SiO_{1/2}$ , siloxane units expressed by the formula  $(CH_3)_2HSiO_{1/2}$ , and siloxane units expressed by the formula  $SiO_{4/2}$ ,

5 an organopolysiloxane composed of siloxane units expressed by the formula  $(CH_3)_2HSiO_{1/2}$ , siloxane units expressed by the formula  $CH_3SiO_{3/2}$ ,

an organopolysiloxane composed of siloxane units expressed by the formula  $(CH_3)_2HSiO_{1/2}$ , siloxane units expressed by the formula  $(CH_3)_2SiO_{2/2}$ , and siloxane units expressed by the formula  $CH_3SiO_{3/2}$ ,

a dimethylhydrogensiloxy-terminated polydimethylsiloxane,

10 a dimethylhydrogensiloxy-terminated copolymer of methylphenylsiloxane and dimethylsiloxane, and

a dimethylhydrogensiloxy-terminated copolymer of a methyl (3,3,3-trifluoropropyl) siloxane and dimethylsiloxane.

15 [0019] Preferably the viscosity of the cross-linking agent (C) at 25°C is in a range of from 2 to 100,000 mPa·s. It is recommended that component (C) be added in an amount such that the mole ratio of silicon-bonded hydrogen atoms in the cross-linking agent (C-2) to the mole number of alkenyl groups in component (A) is in the range of from 0.1:1 to 1:1, more preferably it is in the range of from 0.5: 1 to 0.9:1. If the above ratio is lower than 0.1:1,  
20 the density of cross-linking will be too low and it will be difficult to obtain a rubber-like elastomer.

[0020] Component (D) the platinum-based catalyst may be any suitable platinum catalyst such as for example a fine platinum powder, platinum black, chloroplatinic acid, an  
25 alcoholic solution of chloroplatinic acid, an olefin complex of chloroplatinic acid, a complex of chloroplatinic acid and alkenylsiloxane, or a thermoplastic resin that contain the aforementioned platinum catalyst. The platinum catalyst is used in an amount such that the content of metallic platinum atoms constitutes from 0.1 to 500 parts by weight per 1,000,000 parts by weight of component (A).

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[0021] The composition may also comprise one or more curing inhibitors in order to improve handling conditions and storage properties of the composition, for example

acetylene-type compounds, such as 2-methyl-3-butyne-2-ol, 2-phenyl-3-butyne-2-ol, 3,5-dimethyl-1-hexyne-3-ol, 1-ethynyl-1-cyclohexanol, 1,5-hexadiene, 1,6-heptadiene; 3,5-dimethyl-1-hexen-1-yne; 3-ethyl-3-buten-1-yne and/or 3-phenyl-3-buten-1-yne; an alkenylsiloxane oligomer such as 1,3-divinyltetramethyldisiloxane, 1,3,5,7-

5 tetravinyltetramethyl cyclotetrasiloxane, or 1,3-divinyl-1,3-diphenyldimethyldisiloxane; a silicon compound containing an ethynyl group such as methyltris (3-methyl-1-butyne-3-oxy) silane; a nitrogen-containing compound such as tributylamine, tetramethylethylenediamine, benzotriazole; a similar phosphorus-containing compound such as triphenylphosphine; as well as sulphur-containing compounds, hydroperoxy compounds, or malic-acid derivatives.

10

[0022] The aforementioned curing inhibitors are used in an amount of from 0 to 3 parts by weight, normally from 0.001 to 3 parts by weight, and preferably from 0.01 to 1 part by weight per 100 parts by weight of component (A). Most preferable among the curing inhibitors are the aforementioned acetylene-type compounds, which demonstrate the best

15 balance between storage characteristics and speed of curing when they are used in a combination with aforementioned component (D).

[0023] Where required one or more adhesion promoters may also be used to enhance the adhesion of the encapsulant to a substrate surface. Any suitable adhesion promoter may

20 be utilised examples include

vinyltriethoxysilane,

acrylopropyltrimethoxysilane,

Allyltriethoxysilane,

glycidopropyltrimethoxysilane,

25 allylglycidylether

hydroxydialkyl silyl terminated methylvinylsiloxane-dimethylsiloxane copolymer,

reaction product of hydroxydialkyl silyl terminated methylvinylsiloxane-dimethylsiloxane copolymer with glycidopropyltrimethoxysilane; and,

bis-triethoxysilyl ethylene glycol (reaction product of triethoxysilane with ethylene glycol).

30

Preferred adhesion promoters are

- i) hydroxydialkyl silyl terminated methylvinylsiloxane-dimethylsiloxane copolymer,
- 5 ii) reaction product of hydroxydialkyl silyl terminated methylvinylsiloxane-dimethylsiloxane copolymer with glycidopropyltrimethoxysilane; and
- iii) bis-triethoxysilyl ethylene glycol.

10 [0024] Anti-soiling additives may be utilised, where required to prevent soiling when the solar cells are in use, particularly preferred are fluoroalkene or a fluorosilicone additives that has a viscosity of 10000 cP such as fluorinated silsesquioxanes such as for example dimethylhydrogensiloxy terminated trifluoropropyl silsesquioxane.

15 [0025] The inventors have also found a new way of passivating the surface of a solar cell and/or photovoltaic cell which may be encapsulated by any system i.e. using the composition as described in the present invention or the prior art processes and lamination techniques. The coating of the cell surface with a trialkoxysilane results in a primer or passivating layer which has good adhesion to the cell surface and typically to the encapsulant  
20 used, it will passivates the surface to remove any problems with bubble formation due to water presence between the cell and the encapsulant. It will also protect the cell after encapsulation from water ingress. Typically the layer of the passivation coating might be as small as 2µm thick. Preferably the fourth group on such a silane is a further alkoxy group, an alkyl group or and alkenyl group. Preferably the trialkoxysilane is for example, a  
25 trimethoxysilane or trimethoxysilane.

[0026] The liquid encapsulant is designed to cure and therefore harden in a well defined thickness when submitted to infrared or thermal radiation. The use of a liquid silicone encapsulant enables the user to operate a continuous process in which a liquid  
30 encapsulant such as liquid silicone rubber may be applied onto cells by way of dispensing equipment such as for example curtain coaters, spray devices and die coaters and the like.

The modules may be fed continuously using a conveyor for flat rigid substrate such as glass or fed in a roll to roll process for flexible substrates such as stainless steel foils.

[0027] The novel encapsulation material is made of silicone resin that is known for its outstanding UV resistance. With silicone, no need of UV screen additive as described in prior art. The encapsulant described in this invention exhibits a long term UV&V light transmission that allows the maximum light to reach the cell. UV resistance of silicone is well known in the literature including the PV literature, however the commercial exploitation of this feature has been limited by a high total cost and a lack of suitable process to dispense a liquid encapsulation.

[0028] The encapsulant is located between the glass and the cell and its primary function is to protect the cell against mechanical stress arising from temperature changes, its second function is to glue the cell to the glass during the encapsulation process.

[0029] The composition may be cured by any suitable process, for example component (B) may be premixed with components (A) and (C) and then co-cross-linked in the presence of platinum catalyst to form a tough network. Preferably a small amount of a catalyst inhibitor, such as for example ethylhexynol, is added to allow a prolonged bath time of the material. To ensure a long lasting bonding interaction between the encapsulant and all adjacent surfaces, a small amount of alkoxysilane adhesion promoter is added and the ratio SiH/SiVi is lower than 1:1, such as for example 0.6: 1. It is believed that the adhesion promoter migrates to the interface of the encapsulant and reacts irreversibly with adjacent surfaces. This strong adhesion allows the module to function over a wide range of temperatures without or substantially without delaminating.

[0030] A silicone based top-coat may also be utilized as a hard coating when cured which is adapted to protect the encapsulant and solar cells. Preferably the top-coat, where required, comprises components (A), (B), (C) and (D) as hereinbefore described in differing proportions in order to provide a hard outer coating when cured.

[0031] Hence in the case of the preferred top coat, Component (A) preferably is a high molecular weight polymer, component (B) is present in an amount of from 30 to 50 parts by weight of a silicone resin containing at least two alkenyl groups and Component (C) a cross-linking agent in the form of a polyorganosiloxane having at least two silicon-bonded hydrogen atoms per molecule, in an amount such that the ratio of the number of moles of silicon-bonded hydrogen to the total number of moles of silicon-bonded alkenyl groups in component is from 0.8: 1 to 5: 1 and more preferably from 1:1 to 4:1.

[0032] Again additional additives including one or more inhibitors and/or one or more adhesion promoters are preferably included in the composition of the top-coat. In the case where a top-coat is being utilised it is preferred to include anti-soiling additives of the type described in the top-coat alone, i.e. when present in the top-coat no anti-soiling agent is required in the encapsulant.

[0033] The top-coat is designed so as to have a required abrasion resistance to prevent further damage that may occur during transportation or in the field usage. It is tough enough to serve also as the back skin protecting the cell. The combination of encapsulant and top-coat is designed to replace multiple layers and material chemistry of the classical configuration (EVA and fluoropolymer laminate) by 2 layers based on 1 core chemistry. The top-coat preferably covers the entire cell interconnects; it functions as an outer layer i.e. as an environmentally protecting layer.

[0034] Again in the case of the top-coat any suitable process may be used for example, component (B) may be premixed with component (A) and component (C) and then co-cross-linked in the presence of a low level of platinum catalyst to form a tough network. A small amount of a catalyst inhibitor such as ethylhexynol is added to allow a prolonged bath time of the encapsulant. When heated above 90 °C, the mixture initially forms a non transparent two phase system due to the presence of an anti-soiling additive and then becomes highly transparent. To ensure a long lasting bonding of the encapsulant to all adjacent surfaces, a small amount of adhesion promoter is preferably used. It is believed that the adhesion promoter migrates to the interface of the top-coat and reacts irreversibly with adjacent

surfaces. This strong adhesion allows the module to function in wide range of temperature from ambient temperature to extremes without delaminating.

[0035] Both the encapsulant and, where utilized, the top-coat provide homogeneous and transparent silicone films that maintains a high flexibility due to the presence of the linear or substantially linear polymers of component (A). The top-coat has a higher tear resistance than the encapsulant. The anti-soiling additives are added to the top-coat, when present to increase the soil resistance of the material and are used in amounts which will not noticeably affect the abrasion resistance properties of said top-coat. In a blend such as that of the top-coat formulation, the anti-soiling additives migrate and spread rapidly at the silicone/air interface making a low surface energy surface but remain chemically bonded to the silicone matrix. The soil accumulation on the top side of the coating is inversely proportional to the surface energy, which is related to the level of anti-soiling additives on the surface.

[0036] In use when a top-coat is provided in addition to the encapsulant, during the cure of the top-coat several phenomenon occur when anti-soiling additives are included in the composition; first a surface phase separation occurs; the anti-soiling additive migrates to the surface and then reacts with the cross-linker giving a fluorine covered surface. The platinum concentration at the surface increases due to inhibitor evaporation, leading to a gradient cure rate of the film from the surface to the bulk. The overall result is a much harder surface and smoother bulk material that allows stress relaxation interface between the glass and the wafer.

[0037] In one aspect, the invention features a transparent encapsulant formed of a silicone composition that provides good adhesive properties to the front glass and to the crystalline silicon cell (or thin film modules). In case of interconnected crystalline solar cells, the encapsulant plays the role of potting material, showing a good adhesion to the interconnect cells, to the connecting wires and to the front glass (wafer modules). The adhesion of the encapsulant to crystalline silicon solar cells requires a good wetting of the cell. It was demonstrated that such wetting is obtained using the adhesive layer, which is of lower viscosity than the top layer.

[0038] In another aspect of the present invention there is provided a continuous method of encapsulating solar modules.

[0039] The current standard industry process generally utilizes an EVA thermoplastic encapsulant and a laminatable backing material such polyester/tedlar and the cell or array of cells/module is prepared using a lamination technique. Typically a suitable laminator is used to laminate the following "sandwich" of layers.

- 1) superstrate glass,
- 2) EVA,
- 3) solar cell array,
- 4) EVA, and
- 5) backing material laminate,

The standard process uses the laminator apparatus to melt the layers of the "sandwich" at a temperature in the region of 140°C (actual temperature used is determined by the actual composition being laminated) under vacuum for about 20 minutes per panel. After lamination the next step of the batch process is tape or sealant framing the cells/modules. The overall operation is carried out in a batch mode and is typically relatively slow, and very labour intensive.

[0040] In the present invention, in the case of thin film solar cells on glass, a transparent encapsulant layer is sprayed, coated or dispensed uniformly on both sides of a thin film solar modules and then where required a further coating of the same material or an alternative top-coat composition may be applied in any appropriate way to fully encapsulate the cell or array thereof/module.

[0041] Preferably the encapsulant is a liquid silicone composition as hereinbefore described and the outer layer may be the top-coat as hereinbefore described, however any suitable liquid compositions may be utilized.

[0042] One major advantage of such a process is that the encapsulant is therefore applied to the cell surface without air bubble entrapment, a major problem under current

processes because air bubbles are believed to retain moisture in high humidity conditions and in use cells can be subjected to huge temperature variations. The presence of moisture is detrimental to solar modules as it condenses into liquid water which may induce local corrosion of metallic contacts, on solder, or on silicon cells and furthermore may also cause early delamination of the modules.

[0043] In the case of interconnecting solar cells, the low viscosity curable silicone encapsulant composition in accordance with the present invention is sprayed, coated or dispensed uniformly onto the back of the front glass. Then the interconnected solar cells are further deposited onto uncured silicone. The assembly is then hardened thermally or by infrared radiation in such a way that the encapsulant maintains the interconnect solar cells in place. Then either a further amount of encapsulant or preferably the top-coat composition as described herein is uniformly applied to totally encapsulate the whole cell assembly and the resulting coated cell assembly is then hardened thermally or by infrared radiation, for example in a continuous oven.

[0044] Alternatively a sufficient amount of silicone encapsulant as described in the present invention is sprayed, coated or dispensed uniformly onto a glass substrate and then the interconnecting cells are carefully immersed into a further amount of the encapsulant or when in use the top-coat and subsequently the resulting coated cells are cured and hardened either thermally or by infrared radiation.

[0045] Preferably, the electrical leads of a module treated using either alternative method described above may be coated with encapsulant and optionally top-coat. The leads coated in such a way so that they may be further bonded into the back skin material to form an integral seal. Preferably, the liquid silicone coatings are contained by a thermoplastic or elastomeric frame which also provide additional protection against water ingress at the edge of the panel.

[0046] One very important aspect when compared to the current process is that the entire process in accordance with this aspect of the invention may be automated into an



integrated assembly line with process control and a reduction in the number of operators required to run the process.

[0047] In a preferred embodiment of the process in accordance with the present invention there is provided a continuous process using curtain coaters or the like as a means of coating the encapsulant and protective layer, continuous ovens for curing applied layers, and a multi-axis robot, (preferably six axis) integrated into an automated system. This process may be used for both organic and silicone systems provided the viscosity of the coatings involved are suitable for use in combination with the means of applying the coating such as a curtain coater. Hence preferably the viscosity of the uncured composition is no greater than 50000 cP and most preferably no greater than 40000cP.

[0048] A curtain coater is generally used for processes involving much less viscous liquids and it was imperative for the process of the present invention that the curtain coater used didn't cause frothing and or bubbling. There were several changes required in the stock equipment to handle the higher viscosity liquid. These were oriented mainly to reducing entrained air in the system, since the higher viscosity materials which are typically going to be used in a process in accordance with the present invention may have a tendency to foam or retain air bubbles. Hence in order for the curtain coaters of the prior art to work several measures may be undertaken to render the traditional curtain coaters suitable for the process of the present invention.

- 1) high powered pumps may be required, the usual diaphragm pumps cannot be used since they introduce air into the system also asked for a higher power pump to handle the very high viscosity of the top layer (e.g. 10.000 cS)
- 2) center feed system - lower viscosity liquid can be fed from any position on the coater head, but due to the longer time required for levelling preferably the curtain coaters for use in the present process have a centre feed
- 3) surface feed - lower viscosity liquids can be fed in any submerged depth position (z dimension) from the bottom to the

top of the coater head tank. Normally it is fed in a submerged manner to control splashing. Our system preferably has a surface feed to avoid entraining any air.

- 4) anti-splash "pan" - at the bottom of the curtain fall is provided a rolled metal pan which is provided to contribute to the laminar flow into the discharge and help prevent entrained air
- 5) Feed tanks are preferably both larger (overall capacity) and taller than normal feed tanks used for standard curtain coaters, to allow entrained air bubbles to rise to the surface of the tank according to Stokes law, and again help reduce the entrained air
- 6) the normal operating speed may be lowered as compared to prior art curtain coaters and the lower operating speed range of the coater conveying system was decreased to allow better control of the speed of feeding the glass panels, and thus better control curtain thickness.
- 7) a plurality of several curtain guides were introduced to the coater head to control the width of the curtain and/or allow multiple curtains such as two or three across. This provided coating flexibility and permitted the use of the same coating equipment for the coating of many different sizes of solar panels and arrays and the like.
- 8) a long return pipe and coalescer to remove gross bubbles from the system
- 9) furthermore the curtain coater may also be provided with a semi-continuous vacuum stripper to de-air liquid before feeding it back into the coater head
- 10) and optionally a heating system may be provided to heat the liquid as it approaches the curtain. If we heat the liquid to about 50C, this has the advantage of reducing the viscosity and provide enhances the probability of any microscopic bubbles to rise to the surface.

[0049] The process may for example comprises the following steps:

- 1) a suitable framing material is applied to a cleaned glass panel, preferably this takes place on an XY table onto which the plate had been previously positioned. The framing material is utilized to protect the edges of the panel and importantly provides a moisture barrier, and serves as a dam to contain the liquid encapsulants prior to cure.
- 2) The resulting framed glass panel is conveyed through a continuous oven to fully cure the framing material.
- 3) The panel with the cured framing material is conveyed through a means of applying a layer of encapsulant (preferably by means of a curtain coating operation). Preferably a layer of 300 to 1000  $\mu\text{m}$ , more preferably a layer of about 400  $\mu\text{m}$  of encapsulant material is applied in a very even coat.
- 4) If required the multi-axis robot may pick up a solar array (of interconnected solar cells) using, for example, a vacuum cup gripper, and then dip coats the solar array into a trialkoxy silane primer which is adapted to protect the cells against moisture. This primer also passivates the solar cell surface to assist in the avoidance of bubble formation during the curing process of the encapsulant.
- 5) In the case where step 4 occurs the silane treated array is then dried preferably by use of the robot. The robot then places the primed solar cell array onto the framed panel, and into the layer of encapsulant, using for example a slow six axis motion wherein in such cases a final, very accurate placement of the cells occur provided by a seventh axis on the gripper. Preferably this placement is done on an extremely flat

"engineered" table that provides very accurate repeatability of placement. This table solves the many tolerance issues inherent in the glass and the solar cells. Preferably this engineered table has a built-in heater that cures the encapsulant layer within a few minutes and thus fixes the cells into a permanent position after which the robot is adapted to release the vacuum and the panel moves to the next step. However, alternatively the glass/cell/encapsulant combination may be cured in a continuous oven.

[0050] The resulting post-cured panel "assembly" is then conveyed through a second curtain coater where a layer of about 500  $\mu\text{m}$  of the protective layer is applied in a very even coat.

[0051] The assembly having had the protective layer applied is then conveyed through a continuous convective/IR oven where the protective layer liquid cures into a smooth tough backing material.

[0052] The final framed panel is then conveyed into a staging area which is similar and may even be the same as for existing systems where the electrical junction box is attached, and the panel is either packaged or goes progresses where required to an aluminium framing step. Our thermoplastic framing material also helps in this step because the cured framing material is bolted into an aluminium profile without any "squeeze out". This squeeze out of excess frame protection material is a problem with the double sided tape or sealant that is currently used in the industry, since it requires trimming and glass cleaning.

[0053] The entire process in accordance with the present invention is an automated assembly line, or continuous unit-operation manufacturing, using electronic process control such as PLC. There are sensors, conveyors, and buffering areas (for any mis-matches in rates of particular unit-operations). Preferably the continuous process of the present invention provides one linear meter of panel per minute which is a significant improvement over the current production speed.

## DRAWINGS

- [0054] FIG. 1 illustrates a conventional solar cell module with a Tedlar/EVA  
5 laminated backskin. The module shows a front glass, and interconnected solar cells  
sandwiched between 2 EVA sheets. The module is edged with rubber seal that make the  
junction to the aluminium frame.
- [0055] FIG. 2: illustrates a further conventional thin film solar cell module with a  
10 TEFZEL outer layer, a thin film silicon solar cell on stainless steel substrate, sandwiched  
between 2 EVA sheets.
- [0056] FIG. 3 : illustrates a solar module with a perimeter aluminium frame, a front  
15 glass, a junction box and interconnected solar cells encapsulated in accordance with a silicone  
composition of this invention
- [0057] FIG.4: illustrates a wafer module without a classical perimeter aluminium  
frame and classical junction box. The interconnect cells are encapsulated with a silicone  
20 composition in accordance with the present invention. The leads are coated in such a way  
that they may be further bonded into the back skin material to form an integral seal.
- [0058] FIG. 5: illustrates a preferred solar module encapsulation process of this  
invention having an automatic wafer positioning. In this process applications of material are  
applied, typically both will be silicone compositions in which 1st layer is a silicone  
25 encapsulant layer between the solar cell and the glass; the second layer is the abrasive  
resistance back skin which may be formed from the same composition or a harder (when  
cured) op-coat as described above.

## Examples

### Example 1: Preparation of silicone composition of this invention:

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[0059] 35.42 g of  $\alpha,\omega$ -dimethylvinylsiloxyl terminated polydimethylsiloxane having a molecular weight of 62000 g/mole and vinyl content of 0.15%; 7 g of poly(dimethylsiloxane-co-methylhydrogensiloxane) containing 1.45% of hydrogen units; 47.22 g of p-xylene solution of dimethylvinylated MQ resin (63% resin in Xylene) were intimately mixed and the p-xylene stripped out under reduced pressure. After solvent removal, 0.825g of dimethylhydrogen siloxyl terminated trifluoropropyl silsesquioxane and 20 ppm of platinum catalyst dissolved in a low molecular weight vinyl polymer were added to the blend to make the final composition. The silicone composition was coated onto a 20 cm x 20 cm glass panel and cured at 120 °C for 30 minutes. Table 1 gives the ultra violet (UV) & Visual (V) light transmission data of a 200 $\mu$ m film of this composition as compared to commercial EVA film of the same thickness. The silicone composition shows a higher light transmission at 300 and 500 nm and similar transmission at 633 nm. The absorbed UV energy causes EVA to yellow and to brown and this effect is known to affect the visible light transmission.

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Table 1: Comparative Ultraviolet and Visible light transmission as a function of wavelength for EVA (ELVAX) and silicone material prepared in example 1.

Samples	Sample	% Transmittance			
		633nm	500 nm (499.43)	400nm (400.20)	300nm (299.67)
EVA1 (200m)	1	78	75	70	1
EVA3 (200m)	2	85	83	80	0
EVA3 (200m)	3	85	83	80	1
Silicone material 200(m)	1	84	83	81	73
	2	83	82	80	73

5 *Values recorded here are lower than the actual due to the light reflection effect on sample surface*

Example 2: Silicone composition that exhibit higher Taber abrasion resistance than the ETFE /EVA laminates.

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[0060] Film samples of similar composition as the one described in example 1 were submitted to a Taber abrasion tester (Taber 5131 equipped with calibrase CS-10 abrading wheels) while measuring the light transmission change as function of number of cycles.

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Figure 1 indicates that after 40 and 80 cycles, Tezfel has lost 25% and 35% of the light transmission respectively while the silicone encapsulant of this invention has lost only 8% of the light transmission after 100 cycles.

Table 2

Number of Cycles	Tefzel Thickness: 25 $\mu\text{m}$	Silicone Encapsulant Thickness: 100 $\mu\text{m}$	Silicone encapsulant Thickness: 200 $\mu\text{m}$
0	100	100	100
5	80.6	98.3	98.3
20		96.5	96.5
40	76.2	-	-
60	74.2	92.5	94.2
80	70.4		
100		91.1	93.6

Table 2 : % of light Transmission loss as a function of abrasion cycles (Taber 5131, Calibrase CS-10) (1): Tefzel 25 $\mu\text{m}$  (2) and (3) silicone encapsulant of this invention having 100  $\mu\text{m}$  and 200 $\mu\text{m}$  thickness. A laminate of EVA/TEFZEL having 200 $\mu\text{m}$  thickness did not show higher abrasion resistance than sample 1.

Example 3: Shore A Hardness of cured silicone compositions in accordance with the invention showing a gradient toughness from the surface to the bulk.

[0061] Samples of similar composition as the one described in example 1 were cured in an aluminium cup to make 3 mm thick flat samples. The catalyst concentration was varied from 3.6 ppm to 7.1 ppm and the samples allowed to cure for 30 minutes at 120 °C, Figure 2 shows the variation of hardness in shore A for both top surface and the bottom surface of the sample as a function of catalyst concentration. At 2.8 ppm, the sample is skinned at the surface but do not fully cure. The example shows that the top surface is harder than the bottom surface indicating a faster or complete cure at the surface than in the bulk. The comparatively high hardness values indicate a high abrasion resistance and good surface properties, while low hardness value (bottom surface) indicates softer material, good for cell protection. Hard material which is in contact with a solar cell surface is likely to induce high stress at the cell/material surface and therefore a potential premature delamination, especially during thermal cycle change.



Pt Catalyst	Hardness (Shore A) Top Surface	Hardness (Shore A) Bottom Surface
3.6	48.4	46.9
4.3	49.5	46.4
5	50.1	47.5
5.7	50.4	47.4
6.4	50.1	47.6
7.1	50.2	48

Figure 2: Variation of Hardness as a function of platinum concentration for the top surface and the bottom surface of a silicone encapsulation of this invention cured in an aluminium cup.

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Example 4: Adhesion of the encapsulant in accordance with the invention onto a glass panel after Damp heat test

[0062] Sample of silicone encapsulant of similar composition as the one described in example 1 were coated onto a 20mm x 20mm glass panel to make a 1000µm thick layer. A 15 mm x 15 mm silicon wafer of 650µm thickness was immersed into the liquid encapsulant and then the assembly cured for 30 minutes at 120 °C. The cured sample was submitted to a humidity/temperature aging test (80 °C/85%RH) for 41 days. No visible delamination could be observed, even after 60 days, the sample was still exhibiting a very good adhesion to the glass.

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Example 5: Coating glass panels with a modified curtain coater of this invention and silicone solar encapsulant of this invention.

20 [0063] 40 kg of the silicone encapsulant of this invention having a viscosity of 7000 cPoise was fed into a curtain coater having 9 kg of polymer hold up and then pumped at 5.5 kg/min to make a nice curtain. 500 x 500 mm glass panels were fed continuously into the coater at 45 m/min to form a polymer film of 70µm, after 6 passes under the curtain, a nice polymer film of 433µm thickness was formed. The glass was then fed at 1 m/min into 1

meter long infrared oven equipped with 4 lamps of 1000 watts each. The sample hardens rapidly to impart a high scratch resistance surface to the glass surface.

5 Example 6: Coating solar glass panels with a modified curtain coater of this invention and silicone solar encapsulant of this invention.

[0064] Example 5 was repeated except that 4 interconnected solar cells were manually glued on to the glass panels using a silicone base adhesive layer of 100  $\mu\text{m}$ . The solar glass with the interconnect on the top side was passed through the curtain at 20 m/min to make a top layer of 200  $\mu\text{m}$ , repeating the coating step once resulted in a solar panel coated with 400  $\mu\text{m}$  encapsulating the interconnect. The top layer is then hardened by passing it at 0.5 m/min in 0.8 m long Infrared tunnel equipped with 8 KW IR lamps from Heraeus.

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CLAIMS

1. A solar module encapsulation solution that comprise a liquid silicone encapsulant and continuous process for encapsulating the solar module.
2. A solar modules encapsulation solution as claims in one where the silicone encapsulant is composed of layers of silicone materials having different molecular weight and molecular weight distribution and different SiH/SiVi ratio. The first layer acts as an adhesive layer protecting the cell from mechanical stress, the second layer acts as an environmental protecting layer.
3. A solar modules encapsulation solution as claims 1 where the adhesive layer is based on a blend of a vinyl functional silicone resin, a low molecular weight vinyl functional silicone polymer and a SiH crosslinker with a ratio SiH/SiVi < 1.
4. A solar modules encapsulation solution as claims 1 where the top layer is based on a blend of a vinyl functional silicone resin, a high molecular weight vinyl functional silicone polymer and a SiH cross-linker with a ratio SiH/SiVi > 1.
5. A solar modules encapsulation solution as claims in one where the silicone matrix composition of both layers contains adhesion promoter to increase a strong and long lasting adhesion of the encapsulant to the adjacent surfaces.
6. A solar modules encapsulation solution as claims in one where the silicone matrix composition is a blend of a functional silicone resin, a functional silicone polymer prepared in a such way that the resin fraction is comprise between 20% to 90%, preferably between 25% to 70% and more preferably between 30 - 60% of from the top layer and 20- 30 % for the adhesive layer.

7. A solar modules encapsulation solution as claims in one where the silicone matrix composition is designed to impart an increased abrasion and a required soil resistance for terrestrial applications.
8. A solar modules encapsulation solution as claims in one where the silicone composition of both layers cures without releasing volatiles.
9. A solar modules encapsulation solution as claims in one where the silicone composition exhibits a light transmission as high as the one of glass.
10. A solar modules encapsulation solution as claims in one where the silicone composition contains inhibitor molecules to allow a prolonged pot life.
11. A solar module encapsulation as claimed in one, where the application process is based on modified curtain coating or other process that allows the deposition of a high viscosity material as uniform thin film coating having a thickness ranging from 20  $\mu\text{m}$  to 1200  $\mu\text{m}$ , preferably between 50  $\mu\text{m}$  to 1000  $\mu\text{m}$ , more preferably between 200  $\mu\text{m}$  to 700  $\mu\text{m}$ .
12. A solar module encapsulation as claimed in one, where the curtain coating or other process is modified to allow the application of a uniform bubble-free film on the top of the cell.
13. A solar module encapsulation as claimed in one, where the combination of the silicone encapsulation with the curtain coating or other process allows the increase of the solar module manufacture throughput.
14. A solar module encapsulation as claimed in one, where the combination of the silicone encapsulation with the curtain coating or other process allows the reduction of the total manufacturing cost of solar module.

15. A solar module encapsulation as claimed in one, where the deposition of the solar cell array into the first layer liquid is by a vacuum gripper. The gripper is controlled by a six-axis robot, or other automatic placement, and a seventh axis or other gripper to controls the placement of the solar cell array into a very thin liquid layer of 100 to 700  $\mu\text{m}$ , more preferably between 200 and 500  $\mu\text{m}$ .
16. A solar module encapsulation as claimed in one, where a thermoplastic or thermo-elastomeric material is framed around the glass substrate of the module. This frame serves to protect the edges of the panel from water ingress. The frame also integrates more easily into the aluminium profile frames currently used in the art without the need for trimming and clean-up.

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FIG. 1

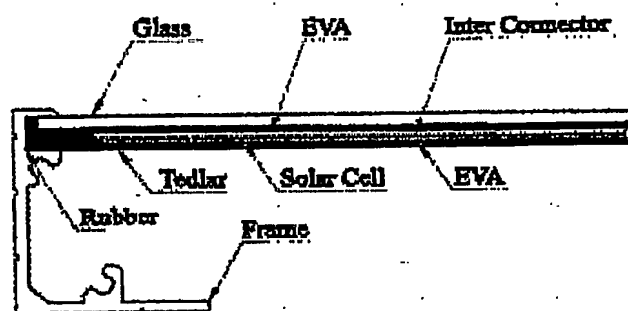


FIG. 2 :

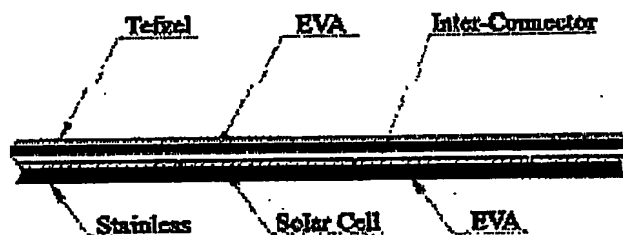
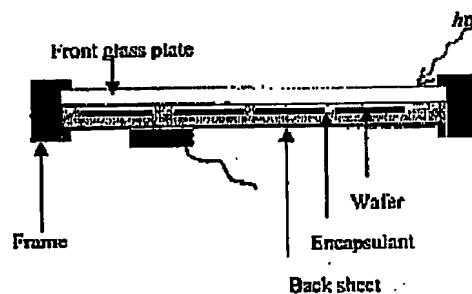


FIG. 3



28

FIG.4:

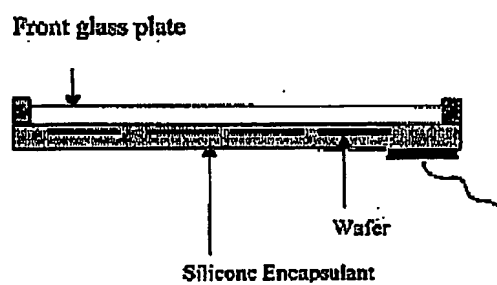
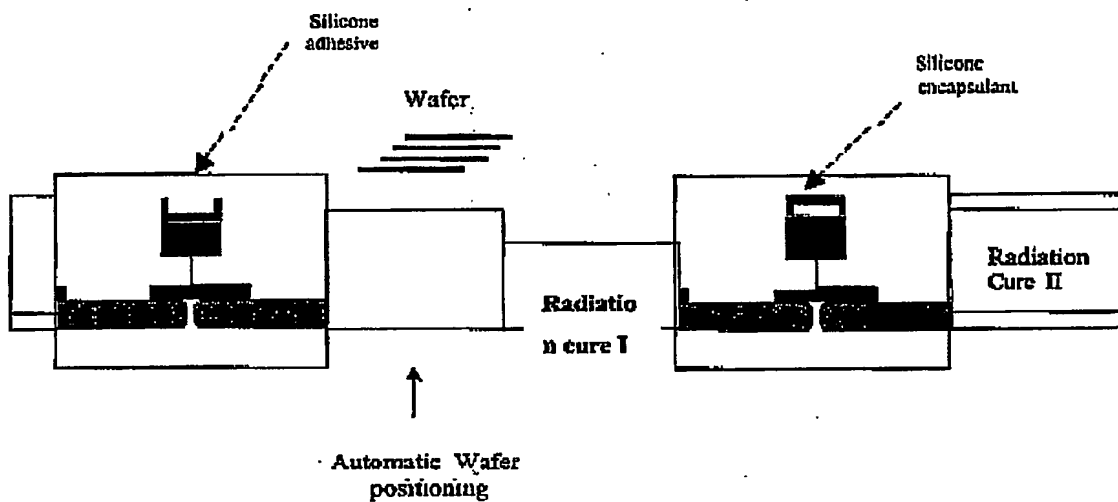


Fig 6



PCT/EP2004/007807<sup>WS</sup>





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